Hydrocode Simulation of Mechanical Asteroid Airburst

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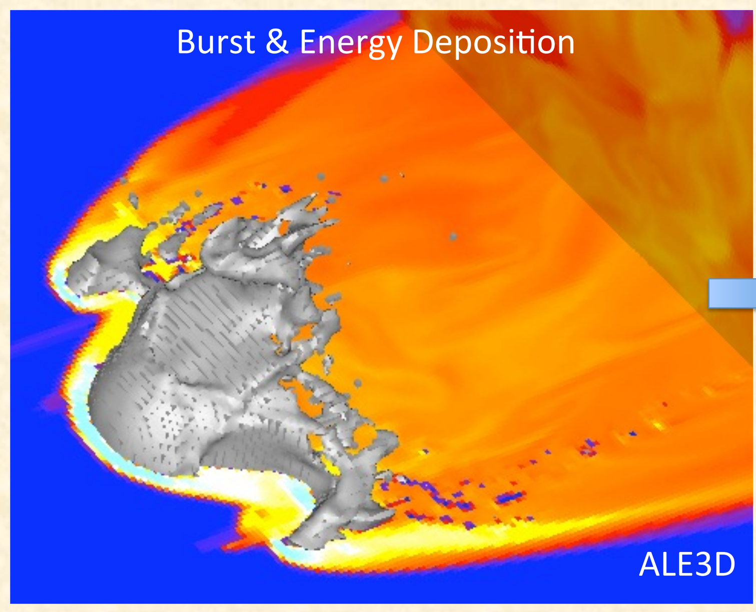
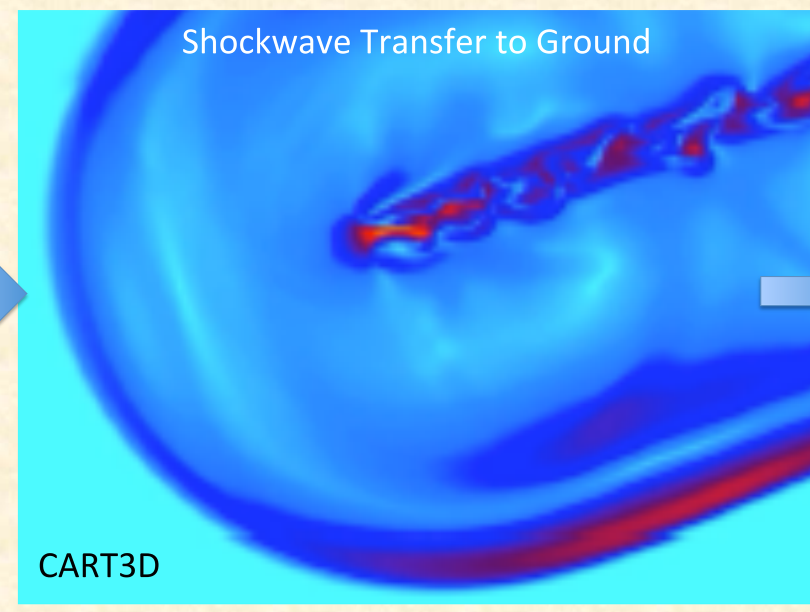
OBJECTIVE & APPROACH

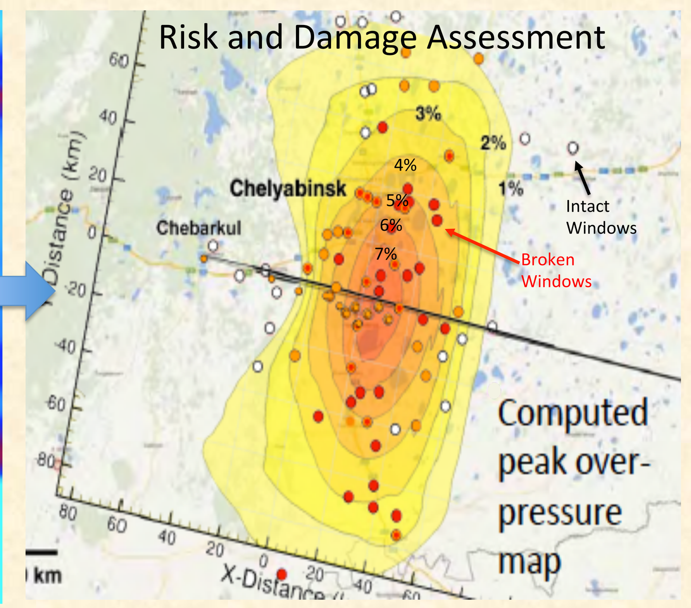
Provide medium to high fidelity estimates of the overpressure and impulse from airburst of an asteroid for use in risk and damage models by using government off-the-shelf hydrocodes to model the mechanical (pressure) break-up, energy deposition, and shock wave formation.

WHY?

- Our aim is to provide short term medium to high fidelity modelling of break-up for a wide range of atmospheric entry conditions and asteroid characteristics such as entry angle, size, shape, strength, and composition.
- Estimates of meteoroid energy from observed damage vary widely: e.g 3 – 700 MT for Tunguska. Most airburst models to date are analytic semi-empirical calculations with many assumptions and simplifications. Hydrocode simulations published to date only include forced burst altitudes or zero strength asteroids for a few select scenarios.

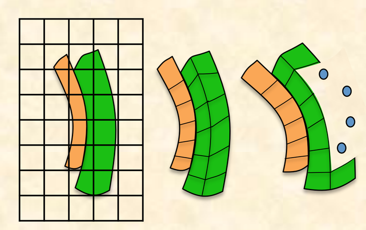






HOW?

- The hydrocode ALE3D from Lawrence Livermore National Laboratory is well developed and validated on a wide variety of impact and fragmentation phenomena and previously used by our group to model launch and re-entry vehicle accidents.
- ALE3D can run in Lagrangian, Eulerian, and Arbitrary modes and also in Smoothed Particle Hydrodynamic and Multiphase flow modes. This provides a wide variety of options for modelling and comparison of solutions.
  - Eulerian or multiphase simulations may be better for modelling rubble piles.
  - Lagrangian or overset Lagrangian/Eulerian simulations may be better for more cohesive or highly fractured asteroids allowing more natural crack propagation and fragmentation.
  - SPH or multiphase models may be better for tracking ablated material and small fragments.
- Our aim is for the asteroid characteristics to be the dominant variables in damage estimates, not the modelling assumptions.



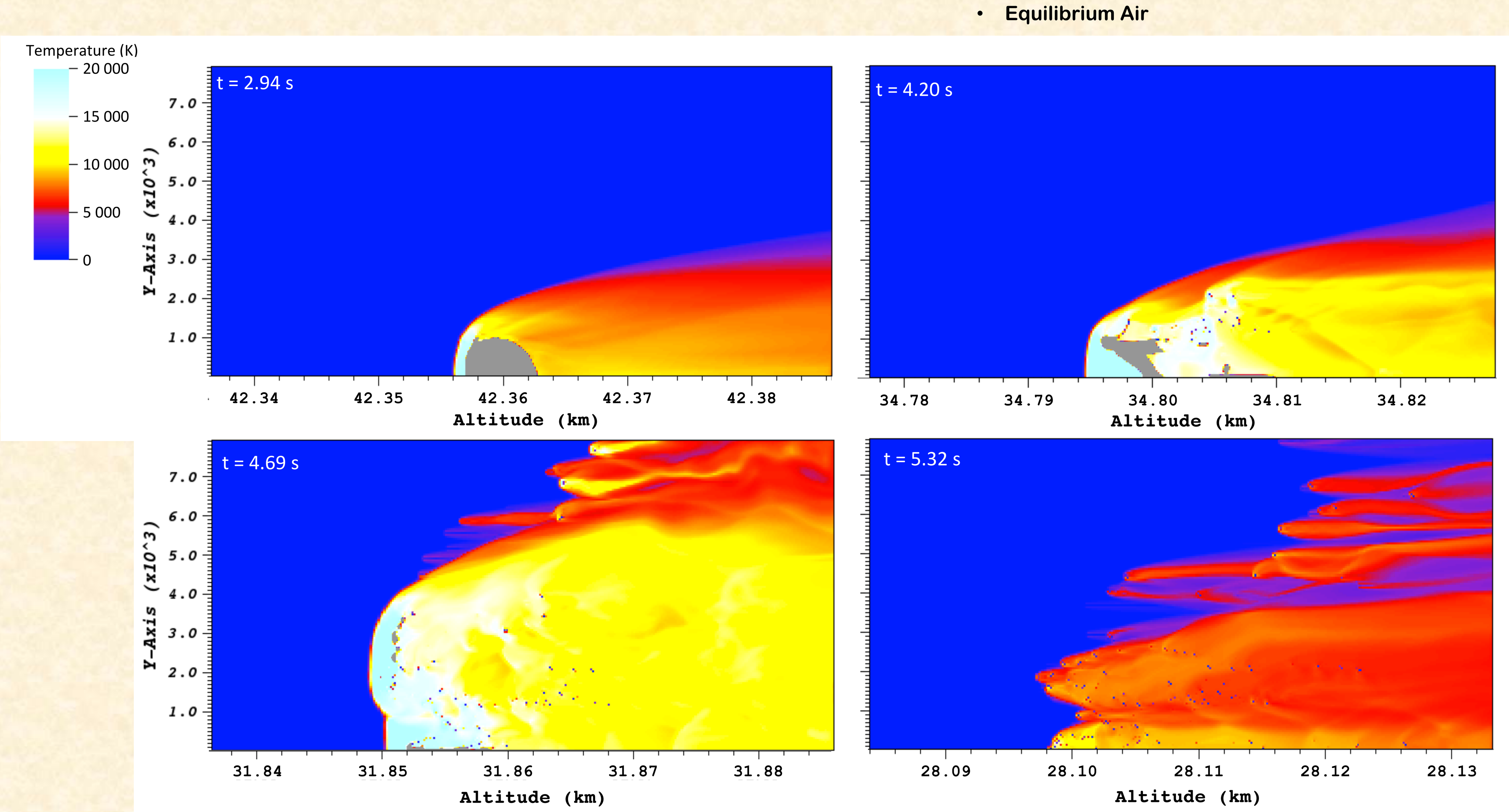
Test case

Chelyabinsk

- Diameter 19.8m
- Entry Angle 18.3°
- Speed 19.16 km/s
- Density 3.3 g/cc

Additional Assumptions:
- Homogenous sphere of rock
- Pre-Failed: No Strength

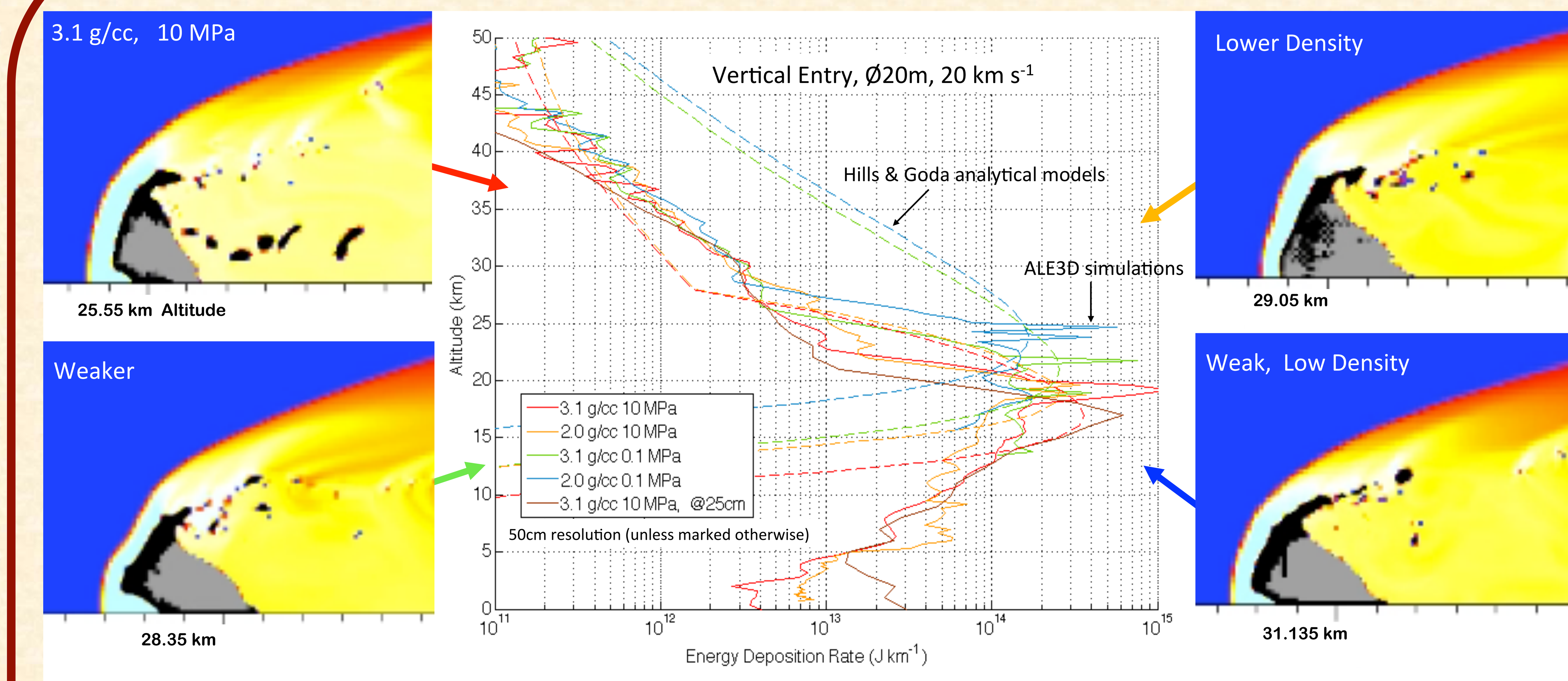
Modelling:
- Eulerian 2-D Axisymmetric
- Pure mechanical break-up
- No heat transfer, radiation, ablation
- Equilibrium Air



Conclusions:
- Fails at slightly higher than observed presumably due to assumption of zero strength.
- Air temperatures higher than would be observed with ablated material and radiation cooling flow but should have minimal impact on pressures which are driving the fragmentation and deceleration.

Strength

Effect of Strength and Density on Vertical Entry of Ø20m Asteroid



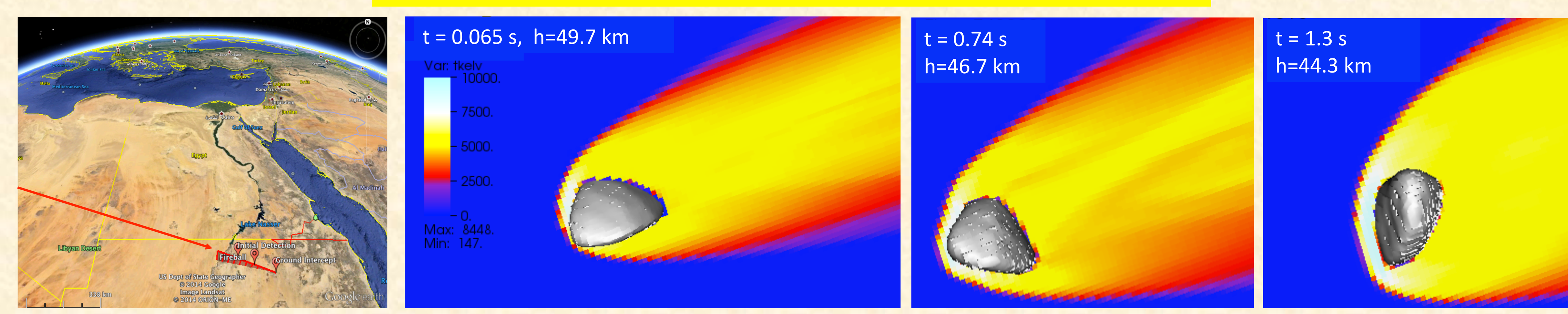
Mechanics of failure:
- All fail on ram surface first.
- All except strong, low density case burst from indentation at axis
- All reach about same max energy deposition rate, but higher density ones have more energy so sustain peak for longer
- Weaker ones fail at slightly higher altitude
- Lower density may or may not fail higher

- ALE3D simulations compare well to semi-empirical analytical models for higher strength asteroids. Hills & Goda model predicts burst when dynamic pressure equals strength, which underpredicts penetration of very weak asteroids.

- Width of energy deposition peaks is sensitive to grid resolution. Smallest can fragment into is 1 cell and deceleration is proportional to cross-sectional area but mass and energy proportional to volume. E.g. a 25cm block will decelerate 4x faster than a 50cm block.
- In ALE3D sub-single cell blocks get stuck on the mesh and advect at the mesh speed not their true speed. This also spreads the energy deposition over a greater distance.
- Ground damage is sensitive to burst altitude. Energy released at a given point spreads out with the square of distance. A higher energy deposition must be larger to have the same ground damage as a lower one (ignoring Mach stem formation). This means it is important to correctly predict the energy deposition curve.

Real Shape

Asteroid 2008 TC3



- Only asteroid to date detected prior to entry whose shape was determined from observations.
- Altitude of burst known from Meteosat and infrasound observations.

Open questions:
- Exact size unknown. Estimates based on observations prior to impact 4 – 27 T depending on albedo and macro-porosity. Estimates from impact models 35 – 108 T. Ranges DO NOT overlap!
- Debris field shows more scatter on large mass fragments than smaller ones
- Does the asteroid have time to trim during entry?

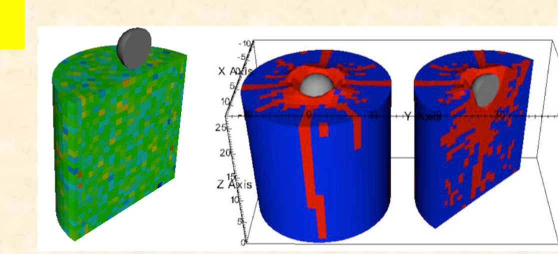
Conclusions to date:
- If modelled as a single cohesive body the shape causes it to rotate in flight even in the few seconds before burst. TC3 was only a few metres across. This may be less significant for asteroids large enough to create significant ground damage.

Anticipated result:
- Energy deposition curve. Hopefully this can shed some light on the disparity between the size estimates.

Future Work:
- Ground debris pattern. Correlation between ground location of meteorites and original location in asteroid.
- Simulate again using multiphase flow to model pebble-pile asteroid and compare with solid boulder model.

Future Work

- Use Lagrangian, Smoothed Particle Hydrodynamics and Multiphase flow simulations to compare to Eulerian simulations and model different types of asteroids.
- Examine effect of asteroid composition, fracturing, and inhomogeneities.
- Improve fidelity of simulations by adding physics such as heat transfer, ablation, radiation.
- Examine larger asteroids which will result in ground or water impact.



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